RANDOM ENGAGEMENT ROLLER CHAIN SPROCKET AND TIMING CHAIN SYSTEM INCLUDING SAME

Cross-Reference to Related Applications

This application is a continuation-in-part of U.S. application Ser. No. 10/004,544 filed December 4, 2001, which is a continuation-in-part of U.S. application Ser. No. 09/321,246 filed May 27, 1999, now U.S. Patent No. 6,325,734, which is a continuation of U.S. application Ser. No. 08/992,306 filed December 17, 1997, now U.S. Patent No. 5,921,879, which claims benefit of the filing date of U.S. provisional application Ser. No. 60/032,379 filed December 19, 1996, and all of said applications are hereby incorporated herein by reference. This application is also a continuation-in-part of U.S. application Ser. No. 10/123,940 filed April 16, 2002, which is a continuation-in-part of U.S. application Ser. No. 09/728,698 filed December 1, 2000, now U.S. Patent No. 6,371,875, which is a continuation of U.S. application Ser. No. 09/383,128 filed August 25, 1999, now U.S. Patent No. 6,179,741, which claims benefit of the filing date of U.S. provisional application Ser. No. 60/097,931 filed August 25, 1998, and all of said applications are hereby incorporated herein by reference.

Background of the Invention

Figure 1 illustrates a known example of a roller chain drive system **10** such as an automotive timing system. The chain drive system **10** includes a drive sprocket **12** and a driven sprocket **14**. The system **10** further includes a roller chain **16** having a number of rollers **18** which engage and wrap about sprockets **12,14**. The roller chain **16** is drivingly engaged with the sprockets **12,14**, both of which rotate in a clockwise direction as shown by arrow **11**.

The roller chain **16** has two spans extending between the sprockets **12,14**; a slack strand **20** and taut strand **22**. In the illustrated example, the sprocket **12** is a drive sprocket and the sprocket **14** is driven by the sprocket **12** by means of chain **16**. As

such, the roller chain **16** is under tension as shown by arrows **24**. A central portion of the taut strand **22** is guided from the driven sprocket **14** to the drive sprocket **12** with a chain guide **26**. A first roller **28** is shown fully seated at a twelve o'clock position on the drive sprocket **12**. A second roller **30** is adjacent to the first roller **28** and is the next roller to mesh with the drive sprocket **12**.

As is generally known, either sprocket **12,14** or both can be an ISO-606 compliant sprocket. For purposes of background only, an ISO-606 compliant sprocket tooth profile is disclosed in Figures 2A and 2B. The tooth space is defined by or comprises a continuous fillet or root radius $\mathbf{R_i}$ extending from one tooth flank (i.e., side) to the adjacent tooth flank as defined by the roller seating angle $\boldsymbol{\alpha}$. The flank radius $\mathbf{R_f}$ is tangent to the roller seating radius $\mathbf{R_i}$ at the tangency point **TP**. A chain with a link pitch **P** has rollers of diameter $\mathbf{D_1}$ in contact with the tooth spaces. The ISO sprocket has a chordal pitch also of length **P**, a root diameter $\mathbf{D_2}$, and **Z** number of teeth. The pitch circle diameter **PD**, tip or outside diameter **OD**, and tooth angle **A** (equal to 360°/Z) further define the ISO-606 compliant sprocket. The maximum and minimum roller seating angle $\boldsymbol{\alpha}$ is defined as:

$$\alpha_{max} = 140° - (90°/Z) \quad \text{and} \quad \alpha_{min} = 120° - (90°/Z)$$

Chain drive systems have several components of undesirable noise. A major source of roller chain drive noise is the sound generated as a roller leaves the span and collides with the sprocket during meshing. The resultant impact noise is repeated with a frequency generally equal to that of the frequency of the chain meshing with the sprocket. The loudness of the impact noise is a function of the impact energy **($\mathbf{E_A}$)** that must be absorbed during the meshing process. The meshing impact energy absorbed is related to engine speed, chain mass, and the impact velocity between the chain and the sprocket at the onset of meshing. The impact velocity is affected by the chain-sprocket engagement geometry, of which an engaging flank pressure angle γ (Fig. 2B) is a factor, where:

$$E_A = \frac{wP}{2000} V_A^2 ;$$

$$V_A = \frac{\pi \ n \ P}{30000} \sin\left(\frac{360}{Z} + \gamma\right);$$

$$\gamma = \frac{180 - A - \alpha}{2}; \text{and}$$

E_A	=	Impact Energy [N*m]
V_A	=	Roller Impact Velocity [m/s]
γ	=	Engaging Flank Pressure Angle
n	=	Engine Speed [RPM]
w	=	Chain Mass [Kg/m]
Z	=	Number of Sprocket Teeth
A	=	Tooth Angle (360°/Z)
α	=	Roller Seating Angle
P	=	Chain Pitch (Chordal Pitch)

The impact energy **(E_A)** equation presumes the chain drive kinematics will conform generally to a quasi-static analytical model and that the roller-sprocket driving contact will occur at a tangent point **TP** of the flank and root radii **R_f,R_i** as the sprocket collects a roller from the span.

As shown in Figure 2B, the pressure angle γ for an ISO-606 compliant sprocket is defined as the angle between a line **L1** extending from the center of the engaging roller **28**, when it is contacting the engaging tooth flank at the tangency point **TP**, through the center of the flank radius **R_f**, and a line **L2** connecting the center of the fully

seated roller **28**, when it is seated on the root diameter D_2, and the center of the next meshing roller **30**, as if it were also seated on the root diameter D_2 in its engaging tooth space. It should be appreciated that γ is a minimum when α is a maximum.

Figure 2B also shows the engagement path (phantom rollers) and the driving contact position of roller **28** (solid) as the drive sprocket **12** rotates in the direction of arrow **11**. Figure 2B depicts the theoretical case with chain roller **27** seated on root diameter D_2 of a maximum material sprocket with both chain pitch and sprocket chordal pitch equal to theoretical pitch **P**. The noise occurring at the onset of roller engagement has a radial component F_{IR} as a result of roller **28** colliding with the root surface R_i and a tangential component F_{IT} generated as the same roller **28** collides with the engaging tooth flank at point **TP** as the roller moves into driving contact. It is believed that the radial impact occurs first, with the tangential impact following nearly simultaneously. Roller impact velocity V_A is shown to act through, and is substantially normal to, engaging flank tangent point **TP** with roller **28** in driving contact at point **TP**.

Under actual conditions as a result of feature dimensional tolerances, there will normally be a pitch mismatch between the chain and sprocket, with increased mismatch as the components wear in use. This pitch mismatch serves to move the point of meshing impact, with the radial collision still occurring at the root surface R_i but not necessarily at D_2. The tangential collision will normally be in the proximity of point **TP**, but this contact could take place high up on the engaging side of root radius R_i or even radially outward from point **TP** on the engaging flank radius R_f as a function of the actual chain-sprocket pitch mismatch.

Summary of the Invention

In accordance with one aspect of the present development, a roller chain drive system comprises a first sprocket; a second sprocket; and a roller chain comprising a plurality of rollers drivingly engaged with the first and second sprockets. The roller chain defines a link pitch P_c. At least one of the first and second sprockets is a random engagement sprocket comprising a first plurality of A-profile teeth formed with a first

asymmetric profile and a second plurality of B-profile teeth formed with a second asymmetric profile that is different from the first asymmetric profile. The A-profile teeth each define a first pressure angle and the B-profile teeth each define a second pressure angle that is at least 5 degrees greater than the first pressure angle.

In accordance with another aspect of the present development, a roller chain sprocket comprises a first plurality of A-profile teeth formed with a first asymmetric profile and a second plurality of B-profile teeth formed with a second asymmetric profile that is different from the first asymmetric profile. The A-profile teeth each define a first pressure angle and the B-profile teeth each define a second pressure angle that is at least 5 degrees greater than the first pressure angle.

In accordance with another aspect of the present development, a roller chain sprocket is adapted to mesh with an associated roller chain having rollers defining a minimum roller radius. The roller chain sprocket comprises a first plurality of A-profile teeth formed with a first asymmetric profile and a second plurality of B-profile teeth formed with a second asymmetric profile that is different from the first asymmetric profile. The A-profile teeth each define a first pressure angle and the B-profile teeth each define a second pressure angle that is at least 5 degrees greater than the first pressure angle. A root surface is located between successive teeth of the sprocket. The root surface is defined by a radius that is smaller than the minimum roller radius to prevent contact between said rollers and said root surface.

Brief Description of the Drawings

Figure 1 (prior art) illustrates one example of a roller chain drive system such as an automotive timing and/or balance system;

Figures 2A and 2B (prior art) partially illustrate a sprocket comprising a plurality of teeth defined according to an ISO-606 standard and show rollers of an associated roller chain meshing therewith;

Figure 3 illustrates a roller chain drive system formed in accordance with the present invention;

Figure 4 illustrates an eighteen tooth random engagement roller chain sprocket formed in accordance with the present invention and that can form part of the system shown in Figure 3;

Figure 5A illustrates one example of an asymmetric tooth profile (an ISO-606 compliant profile is shown in phantom);

Figure 5B partially illustrates a sprocket comprising a plurality of teeth each defined according to the asymmetric profile shown in Figure 5A, and diagrammatically shows chain rollers meshing therewith;

Figure 5C illustrates the asymmetric tooth profile of Figure 5A, and further illustrates a second asymmetric tooth profile overlaid therewith for ease of comparison;

Figure 6A also illustrates first and second asymmetric tooth profiles of the sprocket of Figure 4 overlaid with each other and further diagrammatically illustrates the pressure angle ranges for the first and second tooth profiles;

Figure 6B provides a table that sets forth preferred values in terms of minimum (min) and maximum (max) values for the first and second pressure angles $\gamma_{AT},\gamma_{AT'}$ along with the corresponding minimum and maximum roller seating angles $\beta_{AT},\beta_{AT'}$ for sprockets having different tooth counts Z and corresponding tooth angles A;

Figure 6C graphically illustrates examples of optimized separation of tooth profile pressure angles for random engagement roller chain sprockets formed in accordance with the present invention;

Figures 7A and 7B partially illustrate a random engagement sprocket formed in accordance with the present invention and comprising teeth defined according to both the first and second asymmetric tooth profiles shown in Figure 5C, and further illustrates meshing of chain rollers therewith and modulation of the frequency of initial roller contacts;

Figure 7C is a table that sets forth data from which it can be seen that the frequency of initial roller contacts is effectively modulated in accordance with the present development (the table relates to a twenty-four tooth sprocket formed in accordance with the present invention);

Figure 8 partially illustrates a random engagement sprocket formed in accordance with an alternative embodiment of the present invention wherein the sprocket is defined to include root relief; and,

Figure 9 is a sectional view of another sprocket embodiment formed in accordance with the present invention and including resilient cushion rings to dampen noise and vibration.

Detailed Description of Preferred Embodiments

Figure 3 illustrates a roller chain drive system **110** such as an automotive timing system formed in accordance with the present invention. The chain drive system includes a drive sprocket **112** and a driven sprocket **114**. The system further includes a roller chain **116** having rollers **118** which engage and wrap about sprockets **112,114**. The roller chain **116** is drivingly engaged with the sprockets **112,114**, both of which rotate in a clockwise direction as shown by arrow **111**. At least one of the sprockets **112,114** is formed in accordance with the present invention.

The roller chain **116** has two spans extending between the sprockets **112,114**; a slack strand **120** and taut strand **122**. In the illustrated example, the sprocket **112** is a drive sprocket and the sprocket **114** is driven by the sprocket **112** via chain **116**. As such, the roller chain **116** is under tension as shown by arrows **124**. A central portion of the taut strand **122** is guided from the driven sprocket **114** to the drive sprocket **112** with a chain guide **126**. A chain tensioner (not shown) may be used to tension and control the slack strand **120**. A first roller **128** is shown fully seated at a twelve o'clock position on the drive sprocket **112**. A second roller **130** is adjacent to the first roller **128** and is the next roller to mesh with the drive sprocket **112**. The roller chain **116** defines a link pitch $\mathbf{P_c}$ measured as the center-to-center distance between successive rollers.

The sprocket **112** is shown separately in Figure 4 and is formed in accordance with the present invention. The sprocket **114** can also be formed in accordance with the present invention. The sprocket **112** comprises a hub **150** defining a central bore or recess **152** into which a shaft is received for driving engagement with the hub. A

plurality of teeth **160** project radially outward from the hub **150** and define a circumferentially extending ring that encircles the hub **150**. The sprocket **112** rotates about an axis of rotation **X**. The sprocket **112** is a "random engagement" sprocket and, as such, comprises a first plurality of teeth **160a** that define a first asymmetric profile, and a second plurality of teeth **160b** that define a second asymmetric profile that is different from the first asymmetric profile (the teeth numbered 3,5,6,8,11-14,16-18 form the first plurality of teeth **160a**). As such, the tooth spaces **162** between successive teeth are also asymmetric. The first plurality of teeth **160a** and second plurality of teeth **160b** are preferably arranged in an irregular or "random" pattern, but can also be arranged in a regular pattern relative to each other. The first plurality of teeth **160a** are each referred to herein as "A-profile" teeth and the second plurality of teeth **160b** are each referred to herein as "B-profile" teeth for ease of explaining the present development.

Referring now to Figures 5A and 5B, the A-profile teeth define a first asymmetric tooth profile **AT** that has a steeper engaging flank **Fe** as defined by the roller seating angle **β** and a shallower disengaging flank **Fd** as defined by angle **β'** as compared to the ISO-606 profile shown in phantom. As shown in Figure 5B, the roller seating angle **β** is the angle defined between a first line **L1** connecting the seated roller center when the roller is seated at locations **B,C** as described below and the sprocket center (axis of rotation) and a second line **L2** connecting the same roller center and roller seating location **B**. The asymmetric pressure angle γ is related to the roller seating angle **β** and can be calculated according to:

$$\gamma = \frac{180 - A - 2\beta}{2};$$

where **A** is the tooth angle calculated according to 360°/Z; where Z = the number of sprocket teeth.

With continuing reference to Figures 5A and 5B, a roller **118** is deemed to be in full engagement with the asymmetric tooth profile **AT** when seated in driving contact with roller seating locations **B** and **C** located at opposite ends of a flank seating radius

R_i. The flank seating radius **R_i** is smaller than the minimum radius **$D_1/2$** of the roller **118** so that a small clearance **CL** is defined between the roller **118** and the flank seating radius **R_i**. This structure ensures that the roller **118**, when at full mesh, will make "two-point" contact with the tooth **AT** instead of single point contact as would otherwise occur due to manufacturing tolerances. The root radius **R_i'** that extends from location **C** into the disengaging flank **Fd** of the next tooth can be identical to the ISO-606 radius or can be varied as desired as described further below. In general, the disengaging flank **Fd** can be shaped as desired to facilitate exit of the rollers **118** from the wrap when the chain disengages from the sprocket and moves into the chain span.

Figure 5C illustrates a second asymmetric tooth profile **AT'**, as used for the B-profile teeth, overlaid with the first asymmetric profile **AT**, as used for the A-profile teeth for a sprocket **112,114**. Roller seating location **C** is identical for both profiles **AT,AT'** in the illustrated embodiment, but need not be. Also, in the illustrated embodiment, both profiles **AT,AT'** are identical from seating location **C** into and through the disengaging flank **Fd** to the tip diameter, but the profiles can be different from each other in this regard. Thus, as shown, the tooth profiles **AT,AT'** differ only in the shape of the engaging flanks **Fe,Fe'** as defined by roller seating angles **β_{AT}, $\beta_{AT'}$**, respectively. As shown in Figure 5C, a roller **118** of chain **116** that is fully engaged with the first asymmetric profile **AT** will seat at locations **B,C**, while a roller **118** fully engaged with the second asymmetric profile **AT'** will seat at locations **B',C**. It is preferred, as shown herein, that a roller **118** seated at locations **B,C** and a roller **118** seated at locations **B',C** be located at identical radial distances from the axis of rotation **X** (FIG. 4) of the sprocket **112**. It is also preferred that the seating locations **B,C** and **B',C** be defined such that a common center-to-center distance is defined between two successive rollers without regard to whether the rollers are seated at locations **B,C**, or **B',C**, for all possible combinations of seating locations, i.e., **B,C** -to- **B',C**; **B,C** -to- **B,C**; etc. Referring briefly again to Figures 3 and 4, the sprocket **112** defines a sprocket chordal pitch **P_s** defined as the center-to-center distance between consecutive rollers **118** if the rollers are fully seated at respective roller seating locations **B,C** and/or **B',C** (which cannot occur

except in the theoretical case where the chain link pitch P_c is exactly equal to the sprocket chordal pitch P_s – i.e., the shortest possible chain meshing with a maximum material sprocket). Owing to manufacturing tolerances in commercial applications, the sprocket chordal pitch P_s is always less than the chain link pitch P_c to ensure that the chain will always engage and properly wrap the sprocket. In accordance with the present development, the sprocket **112** is manufactured so that the sprocket chordal pitch P_s is less than the chain pitch P_c by a select amount above and beyond the amount due to manufacturing tolerances so that a roller **118** meshing with an A-profile tooth (a tooth having the profile **AT**) will make initial contact at location **A** (Figure 5C) and a roller **118** meshing with a B-profile tooth (a tooth having the profile **AT'**) will make initial contact at location **A'** (Figure 5C). As described in detail below, it is preferred that the sprocket chordal pitch P_s be at least 0.2% and not more than 1% less than the link pitch P_c of the chain **116**. This intentional reduction in the sprocket chordal pitch P_s relative to the chain link pitch P_c above and beyond the chordal pitch reduction resulting from manufacturing tolerances is referred to herein as "added chordal pitch reduction" or "added CPR."

Figure 6A illustrates another overlay of an A-profile tooth **AT** and a B-profile tooth **AT'**. The A-profile tooth defines a first pressure angle γ_{AT} in a first range and the B-profile tooth defines a second pressure angle $\gamma_{AT'}$ in a second range, and the difference between the first and second pressure angles $\gamma_{AT},\gamma_{AT'}$ is maintained within a third range **Δ**. The first and second ranges for the first and second pressure angles $\gamma_{AT},\gamma_{AT'}$ will vary depending upon the number of teeth **Z** on the sprocket **112**. Figure 6B provides a table that sets forth acceptable values in terms of minimum (min) and maximum (max) values for the first and second pressure angles $\gamma_{AT},\gamma_{AT'}$ along with the corresponding minimum and maximum roller seating angles $\beta_{AT},\beta_{AT'}$ for sprockets having different tooth counts **Z** ranging from eighteen to fifty and corresponding tooth angles **A**. As described further below, when designing a particular sprocket in accordance with the present invention, such as the sprocket **112** and/or sprocket **114**, the values for the first

and second pressure angles $\gamma_{AT},\gamma_{AT'}$ are selected to ensure the required separation **Δ** between the first and second pressure angles $\gamma_{AT},\gamma_{AT'}$ when calculated as follows:

$$\Delta = \gamma_{AT'} - \gamma_{AT}$$

Figure 6C graphically illustrates preferred values for the first and second pressure angles $\gamma_{AT},\gamma_{AT'}$ and the resulting value **Δ** separating the selected first and second pressure angles $\gamma_{AT},\gamma_{AT'}$ for ten different sprockets **S1, . . .,S10** formed in accordance with the present development. In accordance with the present invention, values for the first and second pressure angles $\gamma_{AT},\gamma_{AT'}$ are selected so that the resulting value **Δ** separating the selected first and second pressure angles $\gamma_{AT},\gamma_{AT'}$ is at least 5 degrees. A separation value **Δ** of 5 degrees has been deemed the minimum that will provide effective modulation of initial roller contacts (and thus attenuation of noise and vibration) when rollers **118** of a chain **116** mesh with sprocket **112**.

Figures 7A and 7B illustrate an example of a random engagement sprocket **112** formed in accordance with the present invention. Specifically, the sprocket **112** comprises asymmetric teeth **160a** conformed according to the A-profile and asymmetric teeth **160b** conformed according to the B-profile. The sprocket **112** rotates in a clockwise direction **111** for engagement with rollers **118a-118d** of chain **116** as described. In Figure 7A, a roller **118a** is fully meshed with the sprocket and seated in driving engagement at locations **B,C**, with an engaging flank **Fe** of a first A-profile tooth **T1**. A roller **118b** is shown at the instant of initial contact with a second A-profile tooth **T2**. The initial contact by the roller **118b** is made at location **A** on the engaging flank **Fe** owing to the added chordal pitch reduction as described above. At the instant of initial contact, a first angle **IC1** is defined between the centers of rollers **118a,118b**.

Figure 7B shows that, as the sprocket **112** rotates further, the roller **118b** moves into two-point contact at locations **B,C** of tooth **T2**, and a third roller **118c** makes initial contact with a B-profile tooth **T3** at a point **A'** on the engaging flank **Fe'**. At the instant of initial contact between the third roller **118c** and the B-profile tooth **T3** at location **A'**, a second angle **IC2** is defined between the centers of rollers **118b,118c**, and the second angle **IC2** is greater than the first angle **IC1**. The increased magnitude of the second

angle **IC2** is evidence that the sprocket **112** must rotate through a larger angle in order for a next-meshing roller **118** to make initial contact with a B-profile tooth as compared to the angle through which the sprocket must rotate in order for a next-meshing roller to make initial contact with an A-profile tooth. From this, those of ordinary skill in the art will recognize that the frequency of the initial roller contacts made at points **A,A'** varies depending upon the order of the tooth A-profile teeth and the B-profile teeth. The angles **IC1,IC2** are referred to as "initial contact" angles as defined by the angle that lies between the center of a first roller seated in "two-point" driving contact at roller seating locations **B** and **C**, and the center of a second roller at the instant of its initial contact with location **A** or **A'**.

As such, for two successive A-profile teeth (A-to-A) or a B-profile tooth followed (in terms of order of meshing) by an A-profile tooth (B-to-A), the sprocket **112** must rotate through a first select initial contact angle **IC1** between the successive initial contacts. For successive B-profile teeth (B-to-B) or an A-profile tooth followed (in terms of meshing order) by a B-profile tooth (A-to-B), the sprocket **112** must rotate through a second initial contact angle **IC2** between the successive initial contacts, wherein **IC2>IC1**.

Figure 7C is a table that provides an example of this relationship for a twenty-four tooth sprocket formed in accordance with the present invention. The table of Figure 7C sets forth data from which it can be seen that the frequency of initial roller contacts is effectively modulated. More particularly, it can be seen that the sprocket can be constructed with added chordal pitch reduction (CPR) ranging from 0.05mm to 0.09mm relative to the link pitch $\mathbf{P_c}$ of a chain **116** (the table presumes a link pitch $\mathbf{P_c}$ = 9.525mm). The A-profile teeth are constructed with a roller seating angle $\boldsymbol{\beta_{AT}}$ of 80.5 degrees. The B-profile teeth are constructed with a roller seating angle $\boldsymbol{\beta_{AT'}}$ ranging from 71.5 degrees to 68.5 degrees. The resulting initial contact angles **IC1** and **IC2** are shown. The final column shows the magnitude by which the angle **IC2** is greater than the angle **IC1** as described above.

According to the present invention, it has been found that when the first and second pressure angles $\gamma_{AT}, \gamma_{AT'}$ are within the preferred ranges disclosed herein, and wherein the separation **Δ** between the first and second pressure angles $\gamma_{AT}, \gamma_{AT'}$ is at least 5°, the random engagement sprocket **112** (having anywhere between eighteen and fifty teeth) is optimized for reduction of noise and vibration. Furthermore, when the sprocket **112** forms part of a roller chain drive system **110**, it is preferred to build the sprocket **112** with added chordal pitch reduction (CPR) of at least 0.2% but not more than 1% to move the initial contact points **A,A'** as far radially outward as possible to correspondingly increase the initial contact angles **IC1,IC2** for the initial contacts.

With reference now to Figure 8, a sprocket **112'** formed in accordance with the present invention is partially shown. Except as otherwise shown and/or described, the sprocket **112'** is identical to the sprocket **112** and, therefore, like reference characters including a primed **(')** suffix are used to designate like features. The sprocket **112'** is defined with "root relief" in each tooth space **162'** defined between successive teeth **160'** (the illustrated teeth **160'** are both A-profile teeth simply by coincidence). As used herein, "root relief" is defined as the clearance **CL2** that exists between the roller **118** and the relieved root surface **RR** defined by the root radius **R_i'** when the roller **118** bridges across the root and seats at points **S1** and **S2** on the opposing engaging and disengaging flanks **Fe',Fd'**. The clearance **CL2** results from the fact that the root radius **R_i'** is less than the minimum radius **R** of the roller **118**. Thus, the roller **118** is prevented from contacting the relieved root surface **RR** when the sprocket **112'** rotates to the point that the roller **118** bridges across the root and seats at points **S1,S2** of the opposing engaging and disengaging flanks **Fe',Fd'**, respectively. Defining the sprocket **112'** to include root relief has been found to be beneficial in further reducing noise and vibration. The sprocket **112'** can also have between eighteen and fifty teeth.

Figure 9 shows a cushion-ring sprocket **212** formed in accordance with the present invention. The cushion-ring sprocket **212** comprises a sprocket body **112,112'** as described above, including the annular ring of teeth **160,160'** projecting outwardly from hub **150**. The cushion-ring sprocket **212** further comprises at least one and

preferably two resilient cushion rings **170** secured to hub **150** adjacent teeth **160,160'**. As shown, the cushion-ring sprocket **212** comprises first and second elastomeric cushion rings **170a,170b** connected to hub **150** and located respectively adjacent opposite first and second axial faces of teeth **160,160'**. The cushion rings **170a,170b** are preferably defined from a suitable polymeric material such as nitrile rubber or another elastomeric material. The cushion rings **170a,170b** are located and dimensioned so that links of an associated chain **116** (Figure 3) meshing with the sprocket **212** will impact the cushion rings **170a,170b** at the onset of meshing and compress same to dampen impact between the rollers **118** and the sprocket teeth **160,160'** which, in turn, reduces noise and vibration.

Modifications and alterations will occur to those of ordinary skill in the art. It is intended that the claims be construed as broadly as possible, literally and/or according to the doctrine of equivalents, to encompass all such modifications and alterations.